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TECHNIQUES RESEARCH PROGRAM

EVALUATION OF AN EXPERIMENTAL JET FLUIDIZER FOR REMOVAL OF SAND WAVES IN THE COLUMBIA RIVER

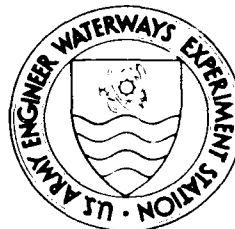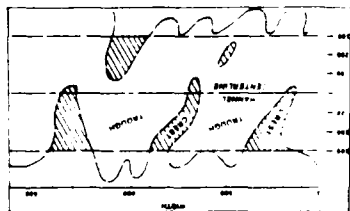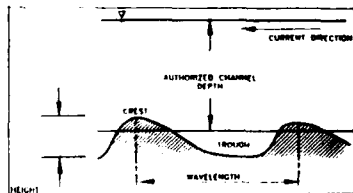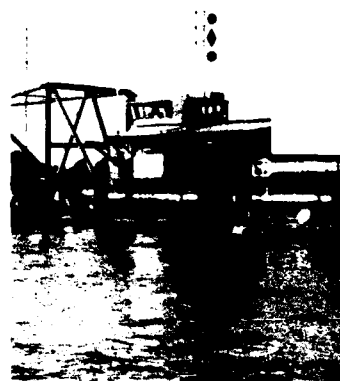## Report 1 DTIC FILE COPY

1987 EXERCISE

by

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Hydraulics Laboratory

DEPARTMENT OF THE ARMY
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HYDRAULICS
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In 1987, the US Army Engineer District, Portland, sponsored an innovative dredging operation to remove sand waves from a portion of the Columbia River navigation channel. Sand wave development and crest protrusion into the navigation channel along the Columbia River is a routine maintenance problem for the Portland District. Sand wave removal with conventional dredging equipment is effective, but often inefficient. A jet fluidizer dredge plant, designed and constructed by Western Pacific Dredging Company, was selected for this exercise. It operated on the concept of hydraulically leveling sand wave crest material into adjacent below-project depth trough sections. This report evaluates the jet fluidizer field performance.

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PREFACE

Field performance of the Western Pacific Dredging Company's jet fluid-
izer for sand wave removal in the Columbia River was evaluated for the US Army
Engineer District, Portland, by personnel of the Hydraulics Laboratory (HL),
US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. Western
Pacific Dredging Company, a division of Riedel International, is headquartered
in Portland, OR. The dredging exercise took place during 23 September-
26 October 1987. Publication of these results was sponsored by the Head-
quarters, US Army Corps of Engineers (HQUSACE), under the Improvement of
Operations and Maintenance Techniques (IOMT) research program, Work Unit
No. 32386, "Mitigating Sand Waves in Navigation Channels." Field data were
collected by Portland District and HL personnel.

The report was written by Mr. William D. Martin, Chief, Estuarine
Engineering Branch, Estuaries Division, HL, and Messrs. Glynn E. Banks and
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Mr. Bob Lofgren, President, Western Pacific Dredging Company; and Mr. Jeff
Lillycrop, Coastal Engineering Research Center, WES, Principal Investigator,
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Commander and Director of WES during preparation of this report was
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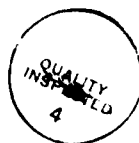
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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurment used in this report can be converted to SI (metric)
units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet of water (39.2° F)	2,988.98	pascals
gallons	3.785412	cubic decimetres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
square feet	0.09290304	square metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings,
  use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings,
  use: $K = (5/9)(F - 32) + 273.15$.

EVALUATION OF AN EXPERIMENTAL JET FLUIDIZER FOR REMOVAL
OF SAND WAVES IN THE COLUMBIA RIVER

1987 EXERCISE

PART I: INTRODUCTION

Background

1. Sand waves, or large sand dunes, are typically found on the beds of
large alluvial rivers such as the Mississippi and Columbia as well as in
coastal estuaries and inlets. They have long plagued the US Army Engineer
District, Portland, along the Columbia River and hindered efforts to maintain
the navigation channel depth of -40 ft* Columbia River Datum (CRD). This
phenomenon builds crest heights in the Columbia that protrude up to 10 ft into
the navigation channel. On the upper Columbia, the sand wave shoals average
five sand waves per 4-mile reach. Heights vary from 6 to 16 ft from trough to
crest. They average several hundred feet in width and 100 to 600 ft in length
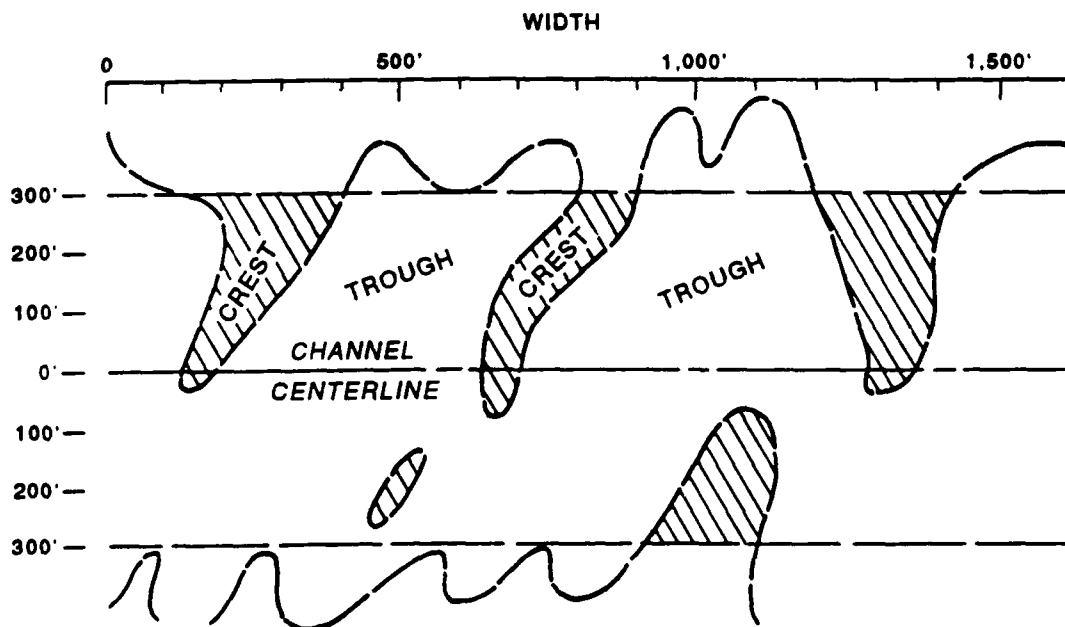(Figure 1).

2. The Portland District has historically used cutterhead pipeline and
hopper dredges to maintain the navigation channel. The pipeline dredges are
most efficient and economical when removing continuous shoals that extend
across the entire channel and are at least 5 ft in height. The hopper dredges
are most useful for removing continuous shoals along the channel that are
several miles in length. The removal of sand wave crests that are neither
extensive nor closely placed is an inefficient use of either type of hydraulic
dredging plant. Efforts to find a more economical and rapidly mobilized type
of plant have been pursued in recent years.

3. The Portland District dredge *Sandwick* has been used to remove small
shoals from relatively shallow areas. The *Sandwick* is an agitation dredge
that uses propeller wash in conjunction with an aft-mounted deflector plate to
suspend shoal material so that it can be transported away by ambient currents.
However, it is effective only to depths of 15 to 20 ft, depending on the

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* A table of factors for converting non-SI units of measurement to SI
   (metric) units is found on page 3.
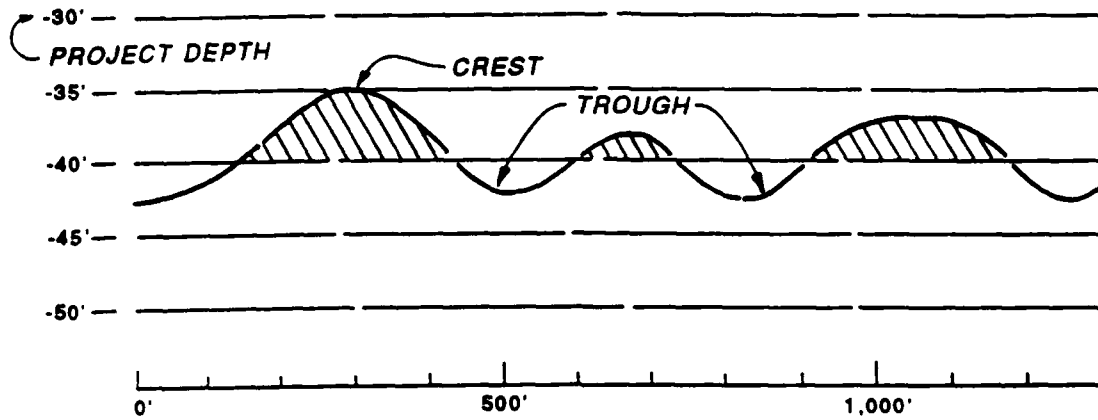
a. Side view

b. Plan view

Figure 1. Sand waves

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channel bottom sediment size,* and therefore not useful in the Columbia River Navigation Channel where depths of 40 ft or greater are encountered.

4. In 1986, the Portland District developed specifications for a sand wave removal plant/device and advertised competitively in the dredging industry for bids for developing such a piece of equipment. Three bids were received with three different approaches. One bidder proposed a submerged pump array to suspend shoal material and allow ambient currents to transport it into the sand wave troughs. Another bidder proposed a barge-mounted pump with an agitation array using closely spaced downward-projecting 1/2-in. nozzles. These were to be mounted on the bottom of a 12-in.-diam pipe, spanning 50 ft. Western Pacific Dredging (WPD), a subsidiary of Riedel International, proposed a jet fluidizer system to scour and suspend shoal material with water jets where ambient river currents could transport the suspended material into trough sections. The WPD system was selected as most viable, and a prototype was constructed. It underwent shakedown tests during the week of 24-28 August 1987, and was placed under contract from 23 September to 26 October 1987.

Corps Specifications

5. The contract specifications required the following capabilities and characteristics of the contractor plant:

a. Ability to mobilize to any reach of the Columbia River between Morgan Bar, river mile 101, and St. Helens, river mile 84, within 60 days after award (see Figure 2).

b. Onboard electronic positioning equipment with ±3-m accuracy. Fathometer capable of determining that a work area is completed and below the designated contract depth of -41 ft CRD. The contractor must make his/her own arrangements for shore station locations.

c. Capability of covering a minimum of 50 ft of width per pass and of reducing the effective crest by 1/2 ft per pass.

d. Ability to work in constantly changing flow velocities, ranging from 2 to 8 fps.

e. Operational techniques that will minimize visible turbidity and sediment in the upper 10 ft of the water column.

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* J. Bechly. 1975 (Sep). "Sandwick Gives Nature a Boost on Shoal Removal," World Dredging and Marine Construction, Vol 11, No. 10, pp 37-41.
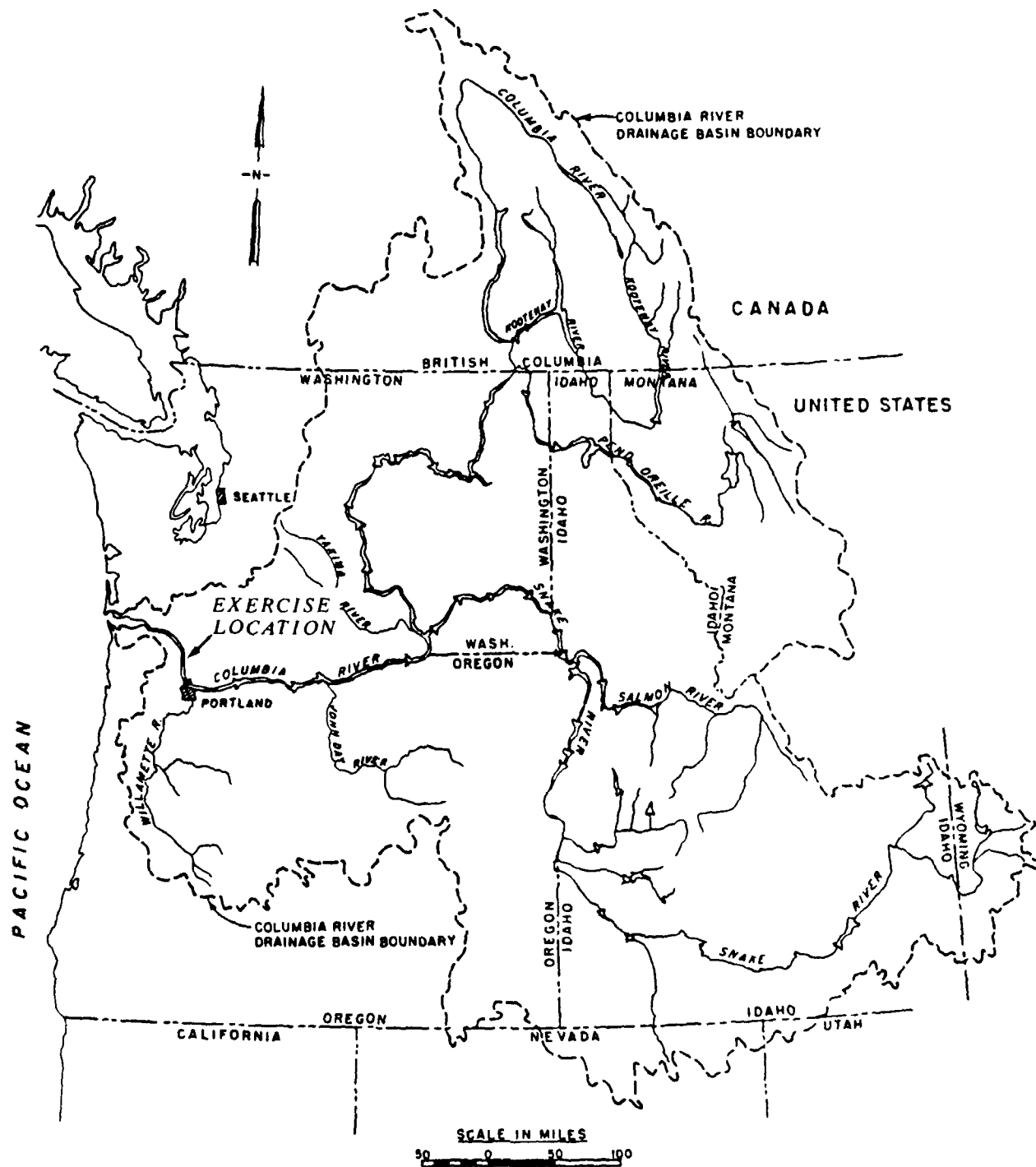
Figure 2. Vicinity map showing exercise location

f. Having pump suction intakes screened with openings no larger than 1 in. to prevent fish from being drawn into the pumping system.

g. Maintaining a minimum average production of 3,000 cu yd per day. Contractor's work period will be approximately 60 days.

h. A work area with minimum postdredged dimensions of 3,000 ft long, 600 ft wide, and contract depth of -41 ft CRD achieved prior to payment. Payment will be based on postdredge surveys.

Objective

6. The objective of this report is to describe and discuss the 1987 field operation and performance of the Riedel jet fluidizer.

PART II: THEORETICAL PERFORMANCE OF THE JET FLUIDIZER

Theory

7.   WPD designed and constructed the jet fluidizer. Their system is shown in Figure 3. The plant consisted of a modified pipeline dredge with a horizontal boom 60 ft wide attached to the dredge by two arms. Water from the pump flowed down one arm and out the nozzles. An A-frame was used to raise and lower the boom. The dredge pump system included a 20-in. dredge pump powered by a 1,500-hp engine. The delivery pipe from the 20-in. pump to the boom was 48 in. in diameter. The piping was arranged to force water through the boom. A jet nozzle with an area of 0.09 sq ft (4-in. diam) was located every 6 ft on the boom. The total flow generated was expected to be about 75 cfs (34,000 gpm), with a system head of 95 ft at the nozzles and an exit velocity of 74 fps (Figure 4). A metal hood was deployed above the boom which WPD believed would induce the system to mimic an eductor pump. The pipe, boom, and hood arrangement are shown in Figure 5.

8.   Conventional eductor pumps operate on the principle of exchange of momentum within the pump.* Clear water, normally supplied by a centrifugal pump, is forced through a jet nozzle into a mixing chamber. The mixing chamber is open to the surrounding environment via suction tube or open nozzle-type construction (Figure 6). In the mixing chamber, turbulent mixing between the jet water and surrounding water/sediment takes place as the jet creates an exchange of momentum. Should the pump be placed in sand, for example, a sand slurry is drawn into the pump. The expanding walls of the diffuser convert some of the jet velocity to pressure energy and the slurry passes on into the discharge pipeline in a continuous process.

9.   The WPD fluidizer hood was designed with open spaces above the jets that were envisioned to act as openings for water entrainment. The jet momentum was expected to entrain this water along with sand from the sand wave crest underneath and form a slurry under the hood. The area under the hood

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*   T. W. Richardson and E. C. McNair, Jr. 1981 (Sep). "A Guide to the Planning and Hydraulic Design of Jet Pump Remedial Sand Bypassing Systems," Instruction Report HL-81-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
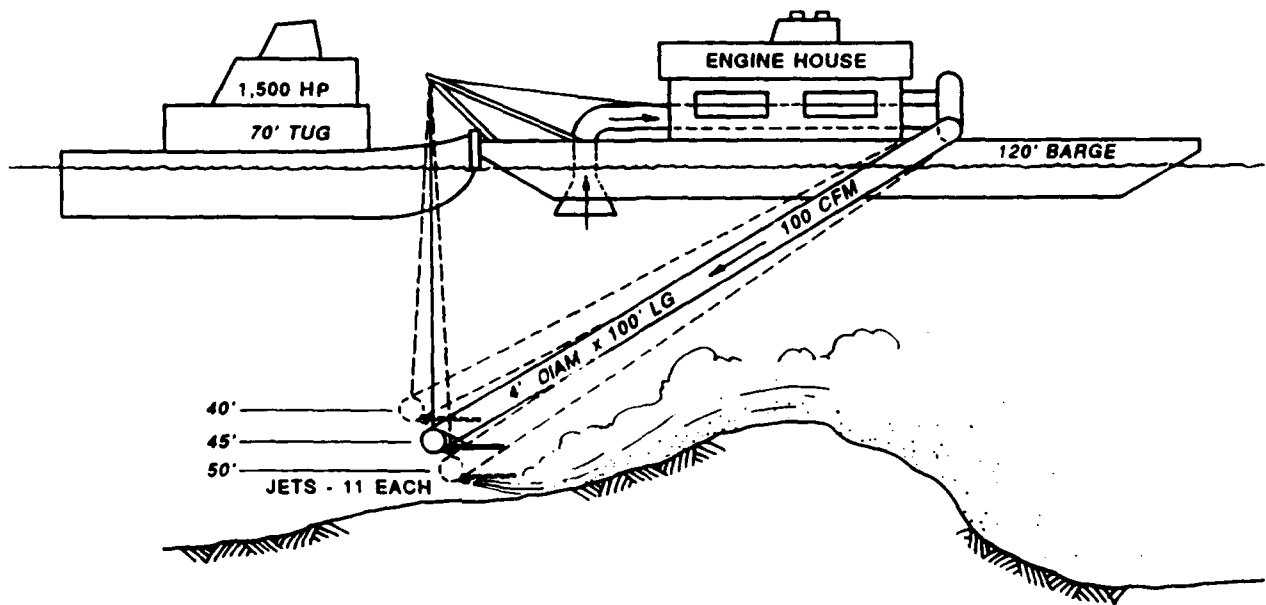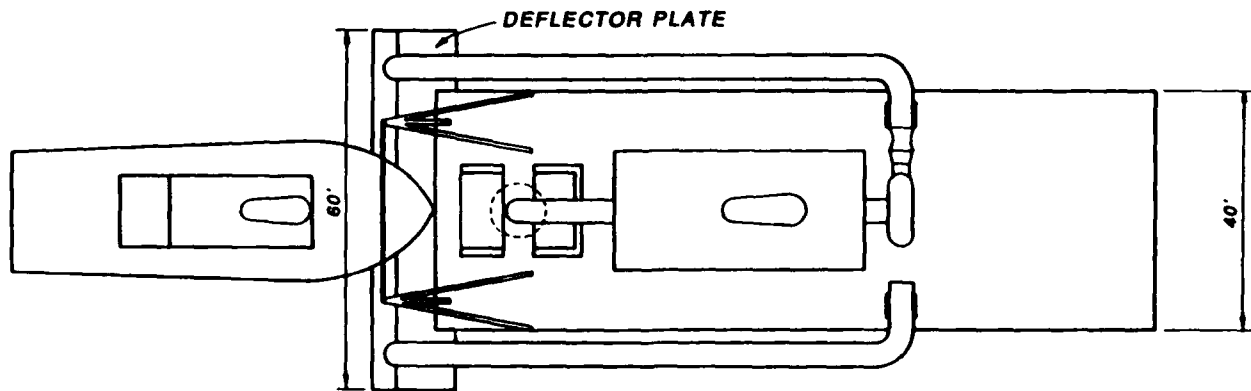
a. Elevation

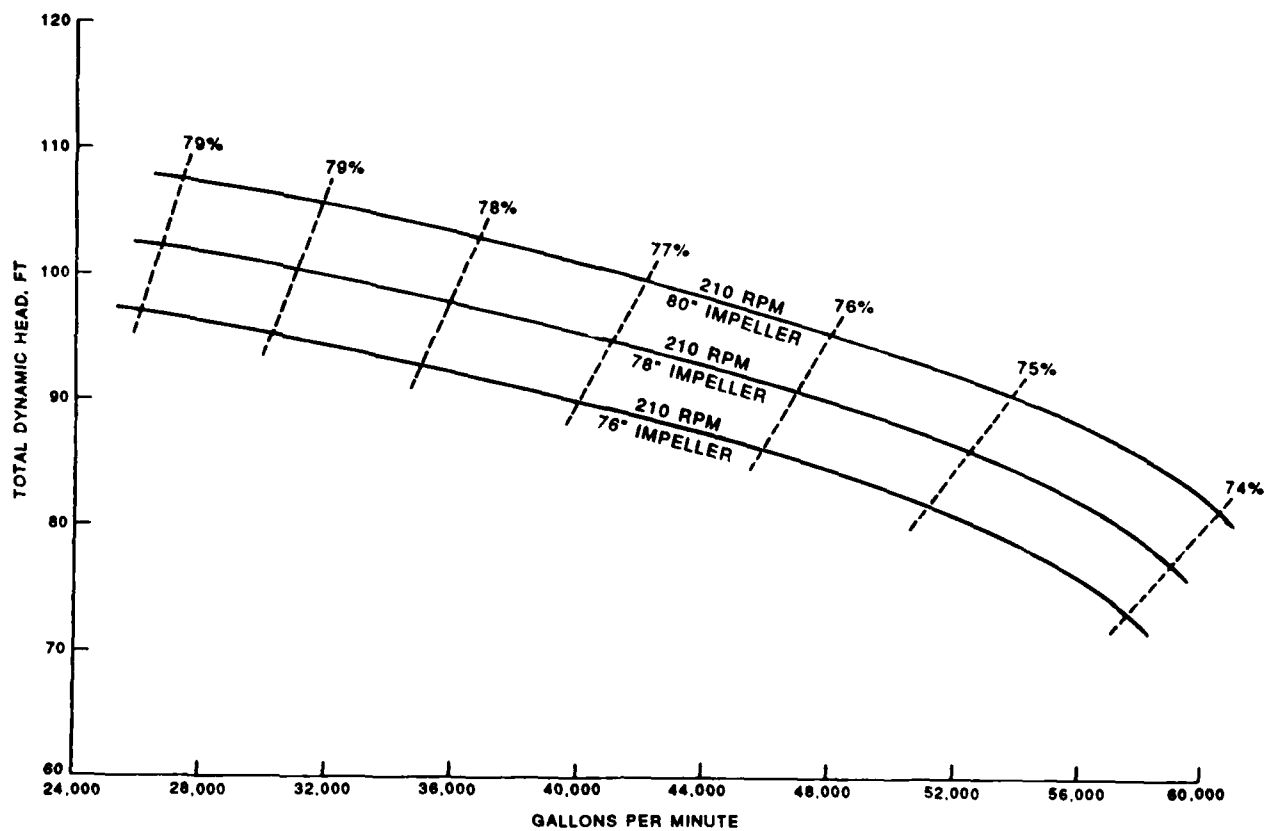Figure 3. WPD jet fluidizer

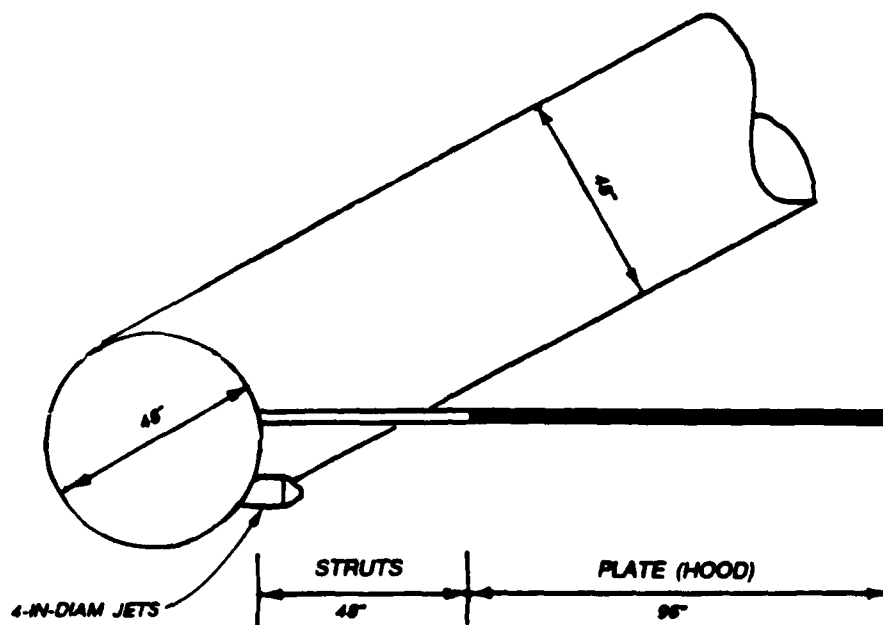Figure 4. Pump efficiency curves

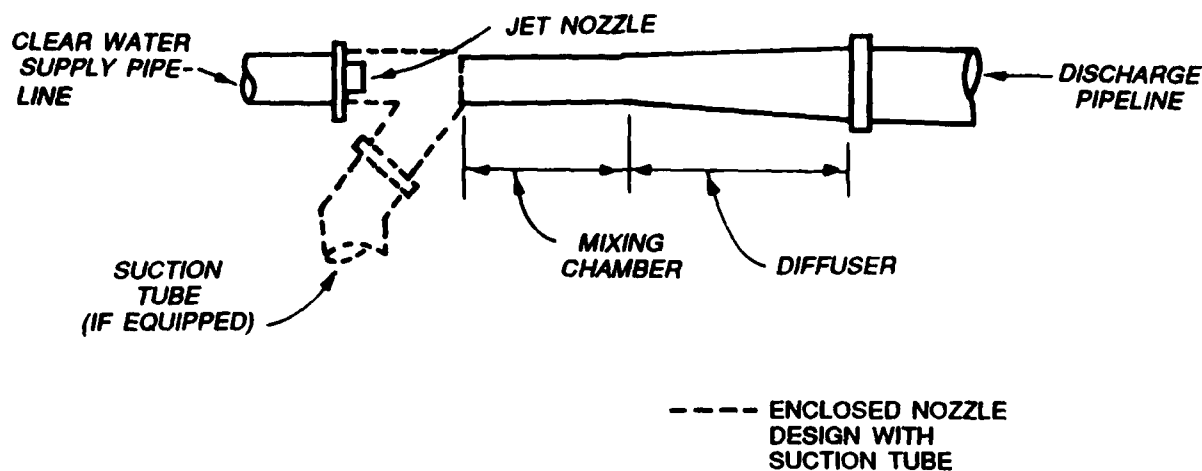
Figure 5. Pipe and boom arrangement

Figure 6. Conventional eductor pump design showing both open and enclosed nozzle-type construction

would serve as the mixing chamber. The river itself was to act as a diffuser. Natural river currents were to assist with material transport into downstream trough sections after the eductor-like jet system fluidized and suspended the sand up and into the water column.

10. It was calculated by WPD that the flow would exit from under the hood at a velocity of 15 fps. Upon leaving the hood area, the sand-water mixture was expected to flow upward at a 30-deg angle with a vertical velocity component of 5 fps. Slurry velocities would then diminish to 1 fps at a vertical height of 20 ft from the bed, some 20 ft below the water surface.

11. Movement of the plant was controlled by a tugboat of approximately 1,500 hp. Horizontal and vertical positioning was accomplished using electronic hydrographic positioning equipment. Fathometers on the tug and dredge recorded bottom elevation after each pass of the unit.

12. Prior to testing, it was envisioned that the nozzle array on the boom would develop a uniform horizontal velocity distribution within 30 ft of the boom. The velocity was predicted to be 15-18 fps at this distance. These predictions were made while ignoring boundary effects of the river bottom. This zone of high velocity, in conjunction with ambient river currents, was to entrain and transport the sand wave material downstream to be deposited in the next trough. The effects of the jets were expected to be significant from 15 to 20 ft above the bed.

Environmental Considerations

13. The Columbia River has a migrant population of small fish, which must be protected during dredging operations Per contract specifications, WPD designed and installed a screen over the pump intake with 1-in.-square mesh openings and a total submerged surface area of 500 sq ft. The resultant velocity through the screen with an intake of 75 cfs was calculated at 0.3 fps. It was felt that this low velocity would allow even small fish to escape the intake flow. There were no instances of fish being caught on the screen or observed swimming inside the screen.

Sediment Transport

14. Before prototype construction, WPD calculated that the theoretical volume of water moved by the fluidizer would be 230,000 cu yd of water per hour. This was based on a total jet discharge rate of 115 cfs. Theoretical sediment transport was then calculated at 14,500 cu yd per hour using the Englund-Hansen approach.* Theoretical sediment transport capability based on the actual prototype discharge rate of 75 cfs was not calculated. Further WPD computations based on the fluidizer boom moving over the bed at 2 fps and removing 1 ft of the sand wave crest per pass yielded a production rate of 16,000 cu yd per hour. These computations were based on short-term contact with the crest of the sand wave as the dredge plant made each pass, and would be accurate only if the fluidizer boom actually removed 1 ft of material per pass and was in continuous contact with the bed. Continuous contact with the bed was impossible to achieve in the field as the dredge had to reposition between passes over the sand wave. Operational difficulties were encountered as well. Much lower hourly production values were achieved as discussed in Part III of this report.

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* Committee on Sedimentation of the Hydraulics Division. 1971. "Sediment Transportation Mechanics: Sediment Discharge Formulas," Journal of the Hydraulics Division, American Society of Civil Engineers, Task Committee for Preparation of Sedimentation Manual, Vol 97, No. HY4, pp 523-567.

PART III: FIELD EXERCISE

Field Configuration

15. The plant as it was deployed in the field and a view of the jet array are shown in Figure 7. The plant specifications conformed with those stated previously in paragraph 5. The angle of the jet nozzles was adjustable from 0 deg, or horizontal to the bed, to 15 deg down, or into the bed. All of the work described in this report was conducted with the nozzles at the 0-deg setting.

Instrumentation

16. The Portland District's hydrographic surveying system was used to perform presurveys and postsurveys. This system, developed by Ross Laboratories, Inc., of Seattle, WA, consists of a 20-ft-long support pontoon barge connected to a 52-ft-long boat, the *Norman Bray*. The pontoon barge supports 16 transducers deployed at 5-ft intervals across two 32-ft-wide booms. The depth readings from these transducers are stored in an onboard computer. The system covers an 80-ft-wide zone of the river bottom with each pass. At the time of this exercise, the data were collected and then transported to the District offices for plotting. The data provide detailed bottom elevation information in the area surveyed and allow computation of volume changes above a reference plane. An example survey plot for the Henrici Bar reach in the vicinity of mile 90 on the Columbia is shown in Figure 8.

Field Operation

17. During field operation, the fluidizer was located on the sand waves by x- and y-coordinates provided by a small contractor's survey boat equipped with a Del Norte positioning system. A similar system was located on the dredge as was an auxiliary fathometer. In summary, the procedure was as follows. The survey system conducted detailed predredge surveys of the reach to be worked. Problem sand waves were located from plots of the survey data. The contractor's survey boat relocated these waves when the dredge proceeded to the area. These coordinates were given to the dredge superintendent and

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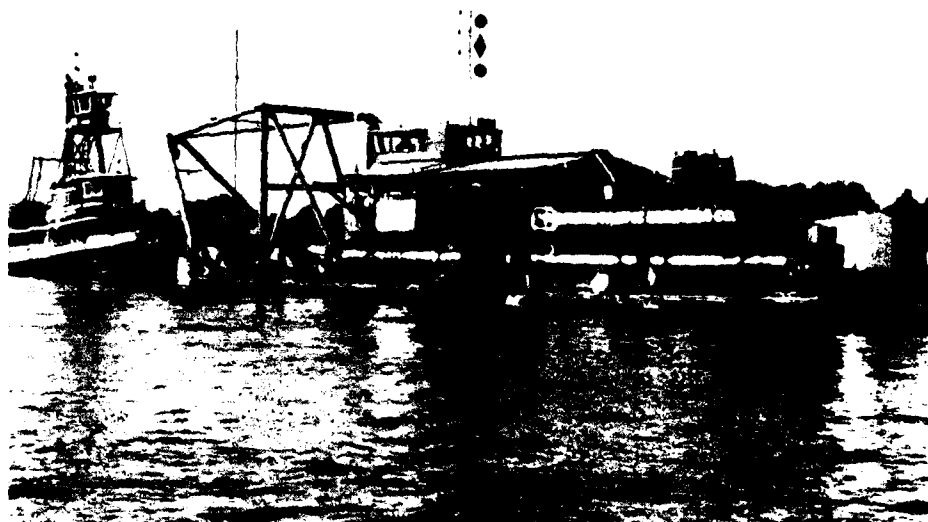
a. Dredge plant

b. Jet array

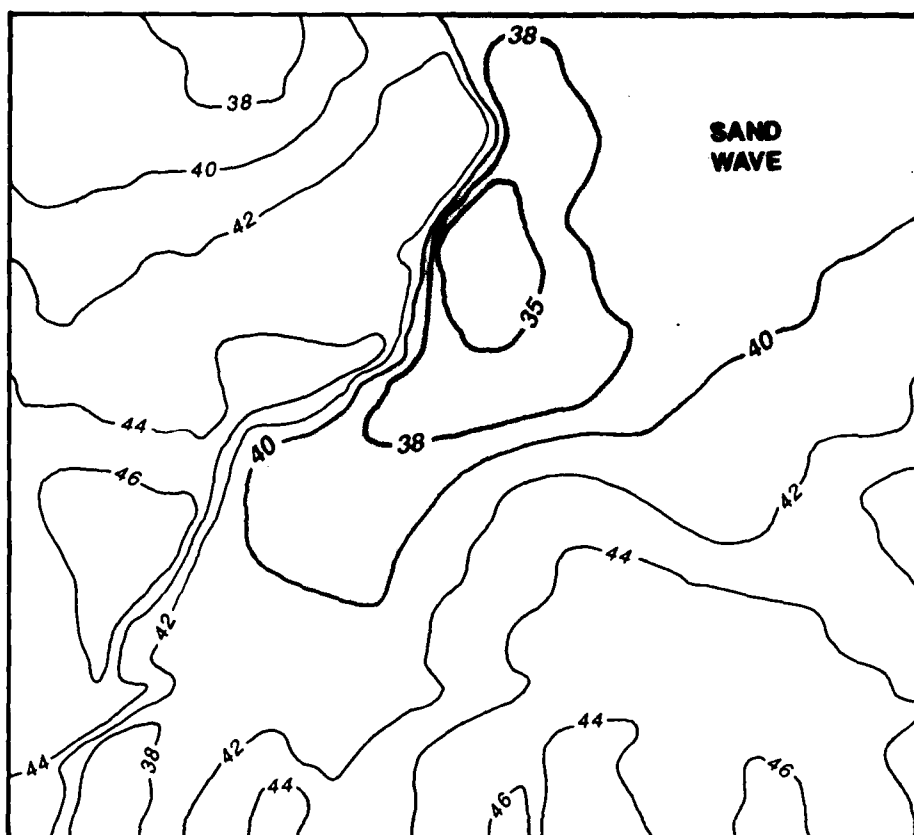Figure 7. Dredge plant and jet array

Figure 8.   Postdredge survey data taken in Henrici Bar
reach, 23 September 1987

then used to compute dredge track lines.   Track line coordinates were then
provided to the tug captain for use in positioning the fluidizer for passes on
the sand wave.   The survey boat checked the progress of the fluidizer as it
approached contract dimensions.   Once the wave was degraded, the survey boat
proceeded ahead to locate the next wave while the slower dredge plant was
moved to the new location.

18.   Limited sediment samples were taken prior to, during, and after the
fluidizer operations with a standard BM 50 bed sampler.   Suspended sediment
samples were also collected with a P 61 sampler.   An attempt was also made to
measure bed transport with a Helly-Smith bed-load sampler.   Velocity measure-
ments were made with Price current meters.   These measurements are discussed
in greater detail in following sections.

Plant Performance

19.   Operationally, the plant proved to be extremely difficult to

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maneuver. Positioning equipment plotted track lines for the tug captain to follow. Initially, it was very difficult to maintain the dredge plant on the track line. One corner of the boom would contact the bottom and in essence anchor the unit. As the captain became accustomed to the unit, the maneuverability improved but required constant adjustment to keep on the track line. The fluidizer would apparently move material for relatively short horizontal distances. Therefore, the initial passes on the sand wave proceeded easily as the crest material fluidized and was transported down the face toward the troughs between sand waves. As the wave crest was lowered, the distance necessary to transport the material increased due to the triangular cross section of the waves. The result was that material redeposited on the crest of the wave. Eventually, a mound of material built up on the wave crest in front of the boom and the boom would bounce over this mound. More than one pass of the boom was then necessary to remove the mound and continue reduction of the sand wave.

Production Efficiency

20. The field effort began on 23 September 1987, and ended on 26 October 1987. During this period, 103,400 cu yd of material was removed based on predredge and postdredge survey calculations. This reduces to 103,400 cu yd removed in 33 days of effort or approximately 3,000 cu yd per day (as per contract specifications). The work days were 12 hours long. There were 313 actual hours of dredging time during the 33 days of the contract. The production rate was therefore 330 cu yd per dredging hour. Another 87 hours were noneffective working time charged to the contract. These noneffective hours were consumed in time traveling to and from the wharf or anchorage, 12 hours; losses due to passing vessels, 17 hours; minor repairs, 31 hours; and preparation and makeup of the tow, 27 hours. A total of 400 hours were charged to the contract, and the production rate per paid hour was 258.5 cu yd.

Data Collection

21. Data in the form of bed material samples, suspended sediment samples, bed-load samples, and velocities were collected at two sites before,

during, and after the sand wave operation.

22. The bed material samples indicated local variations in time and space as one would expect in a sand bed river. The seven predredge samples had a d_{100} grain size, or the largest size present in the sample, that varied between 2.0 and 4.0 mm, with the average d_{100} size 2.9 mm.

	Grain Size, mm								
	Predredging			During Dredging			Postdredging		
Frac-tion	Bed Load	Bed Mate-rial	Suspended Sediment	Bed Load	Bed Mate-rial	Suspended Sediment	Bed Load	Bed Mate-rial	Suspended Sediment
d_{100}	2.8	2.9	0.34	3.3	6.0	1.2	2.4	9.4	--
d_{50}	0.38	0.35	--	0.33	0.30	--	0.43	0.41	--

The ten samples taken during the operation indicate the d_{100} grain size varied from 2.0 to 8.0 mm, with the average size 6.0 mm. Fourteen samples taken approximately 1 month after the initial effort indicate the d_{100} grain size varied from 1.0 to 64 mm with the average d_{100} 9.4 mm. The predredge d_{50} grain size, or that size for which 50 percent of the sample was finer, ranged from 0.28 to 0.41 mm, with the average 0.35 mm. The d_{50}'s collected during the operation ranged from 0.25 to 0.35 mm, with the average 0.30 mm. Fourteen samples collected after the initial effort had an average d_{50} of 0.41 mm. (The sizes reported are percent finer by weight.) Therefore, the fluidizer, based on these limited samples, appears to sort the bed by removing the finer material and thereby shifting the d_{50} to a larger grain size.

23. The suspended sediment samples were taken before and during the sand wave removal operation. The samples taken before the exercise in general indicate the d_{100} grain sizes varied from 0.12 to 1.0 mm with an average d_{100} grain size of 0.34 mm. About 33 percent of the measured suspended load consisted of sand-size particles and 67 percent consisted of silts and clays. The samples taken during the dredging operation indicate that the d_{100} grain sizes varied from 0.50 to 2.0 mm with an average d_{100} grain size of 1.2 mm. About 92 percent of the measured suspended load consisted of sand-size particles and 8 percent consisted of silts and clays. No suspended samples were taken during the postdredging sampling.

24. Bed-load samples typically captured only a trace of material. However, the material captured in the three predredge samples had a d_{100} that

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varied from 2.0 to 4.0 mm. The average d_{100} grain size of the samples collected was 2.8 mm. The average d_{50} of these samples was 0.38 mm. All of the samples collected consisted of sand-size particles with no silts or clays. The three samples taken during the operation had d_{100} grain sizes that varied from 2.0 to 4.0 mm. The average d_{100} of the samples collected was 3.3 mm. The average d_{50} of those samples was 0.33 mm. There were no silts or clays present. The eight postdredge bed-load samples had a d_{100} that varied from 1.0 to 4.0 mm. The average grain size of the samples collected was 2.4 mm. The average d_{50} of these samples was 0.43 mm. There were no silts or clays present. Results of the sediment sampling are presented in the tabulation in paragraph 22.

25. Predredging and postdredging velocity profiles indicated no significant differences. The reach of the Columbia where the exercise took place, between river miles 90+17 and 91+35, is tidally influenced, and any differences in the velocity profiles were due to tidal influences and differences in discharge. The predredging and postdredging velocity comparisons* are shown in Figures 9 and 10 for river mile 90+17 and in Figures 11 and 12 for river mile 91+35.

26. Additional velocity measurements were taken from the dredge during operation. These were taken at the points labeled *A-G* in Figure 13. Figure 14 shows the plotted vertical velocity profiles for the data points in Figure 13.

VELOCITY, FPS

Figure 9. Predredge hydraulic data, river mile 90+17

VELOCITY, FPS

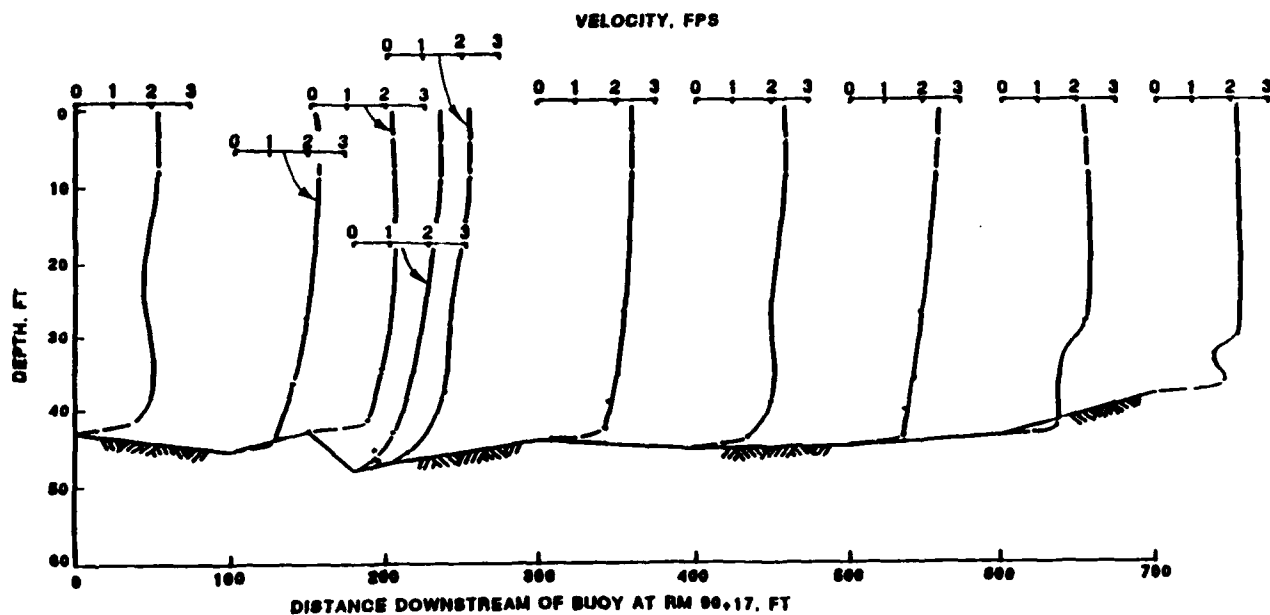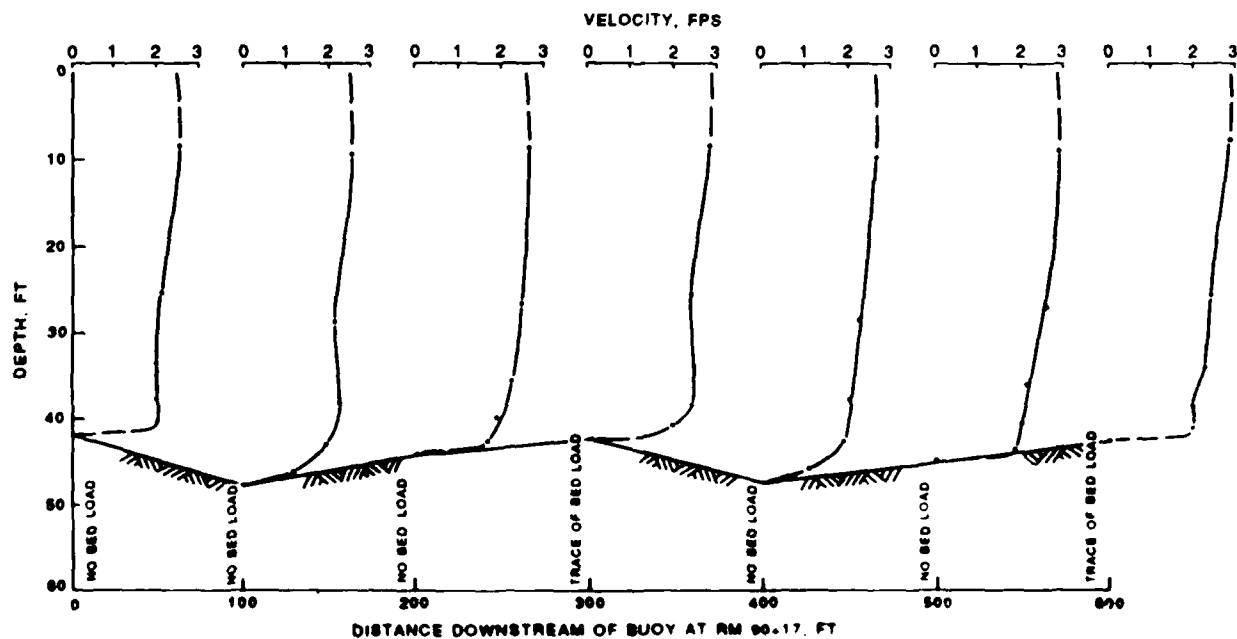Figure 10. Postdredge hydraulic data, river mile 90+17, post-skimmer
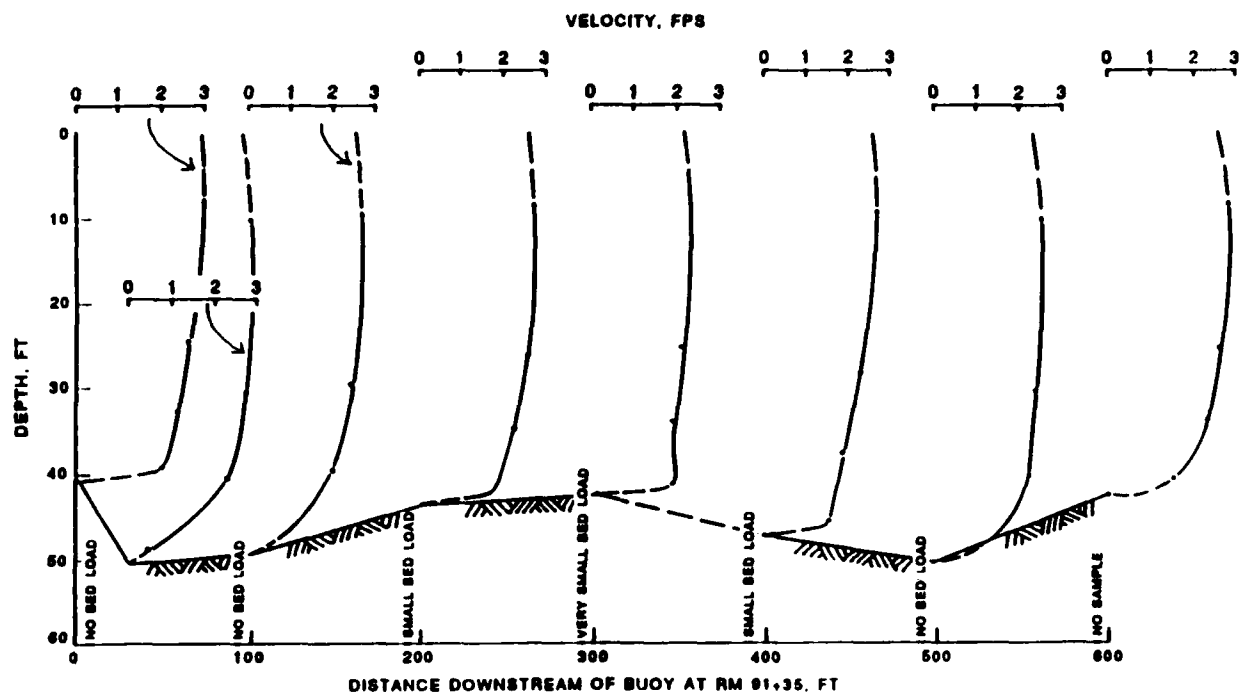hydraulic data

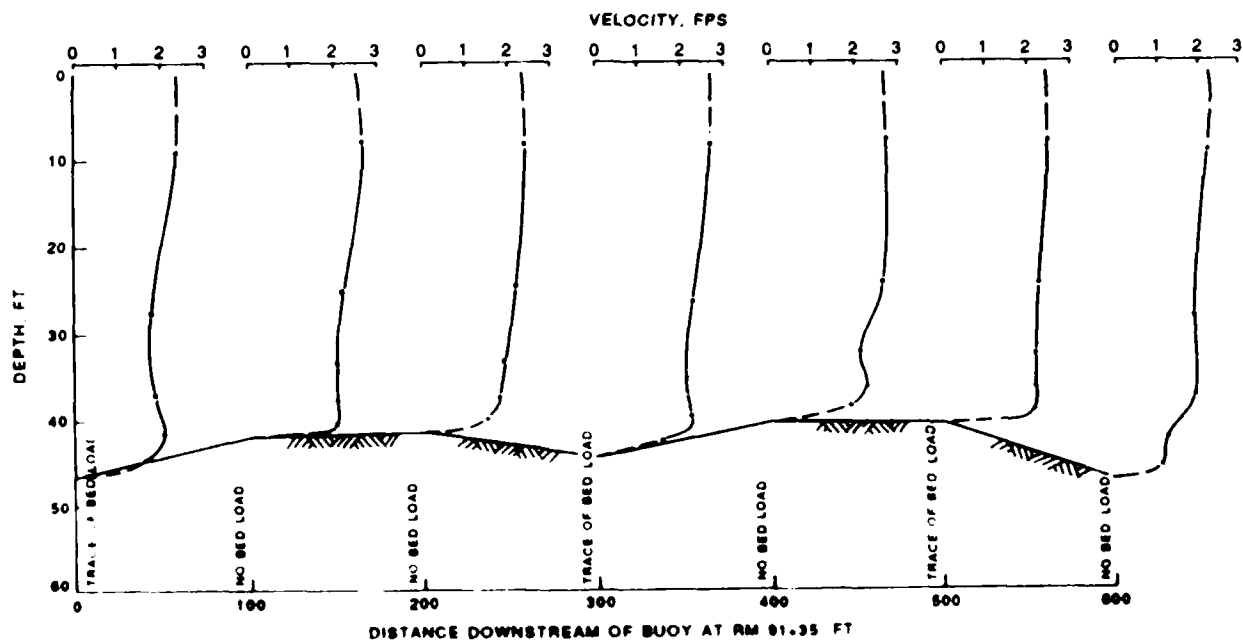Figure 11.   Predredge hydraulic data, river mile 91+35

Figure 12.   Postdredge hydraulic data, river mile 91+35, post-skimmer hydraulic data
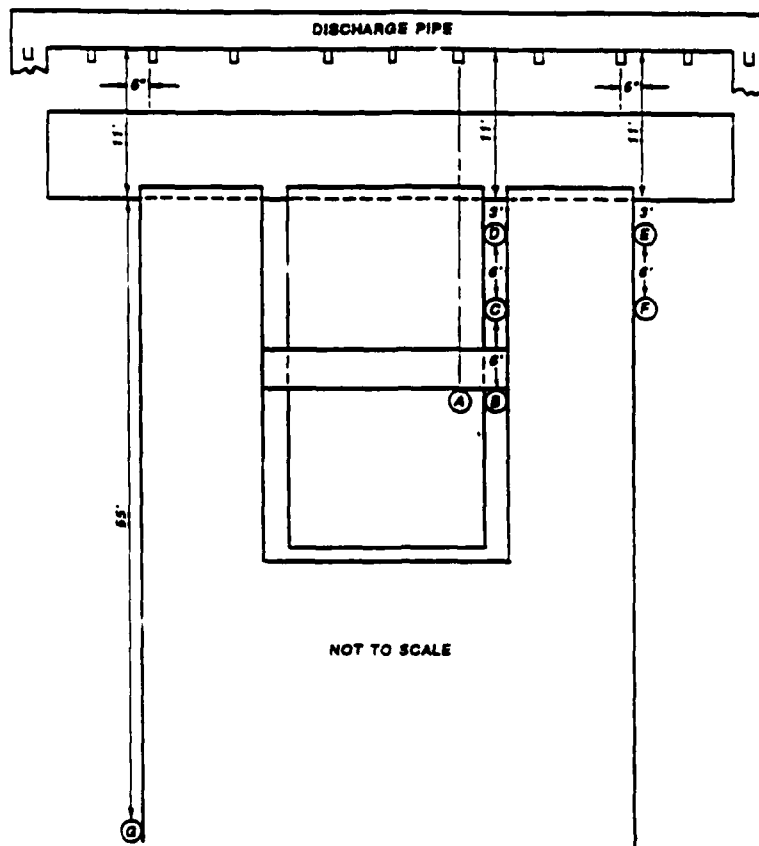
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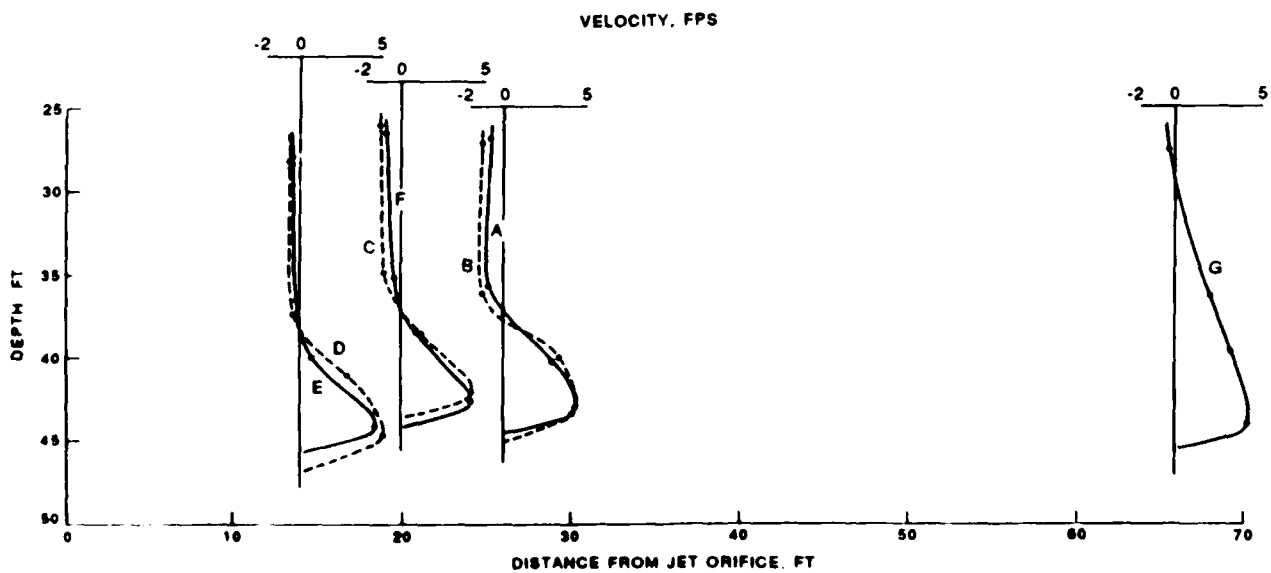Figure 13. Location of field velocity measurements
on the dredge

Figure 14. Field velocity measurements in the vicinity of the dredge

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PART IV: CONCLUSIONS AND RECOMMENDATIONS

Jet Fluidizer Performance

27. As can be seen in Figure 14, the jet fluidizer fell short during field application of attaining the predicted theoretical velocities. Theoretically, with an exit velocity from the jet nozzles of 74 fps, a velocity of 15 fps should have been observed at the end of the hood some 11 ft from the nozzles, based on WPD's calculations. Field measurements 14 ft from the nozzles, points D and E shown in Figures 13 and 14, indicated that the maximum velocities at this point were approximately 5 fps.

28. The jet of water was theoretically envisioned to contact the sand wave, fluidize the sand, and convey the water-sediment mixture in an expanding cone that would diminish to a velocity of 1 fps at a depth of 20 ft below the water surface. The fluidizer was anticipated to create a significant zone of transport 15 to 20 ft above the bed with velocities of 15-18 fps. The horizontal distance over which this effect would be significant was not specified by WPD.

29. In actual practice, the maximum velocity measured was about 5 fps. Based on field measurements taken from the dredge during the operation, the zone of influence extended some 8-9 ft above the bed into the water column at a distance of 25 ft from the nozzles. At a distance of 65 ft from the nozzles, the zone of influence extended about 18 ft above the bed into the water column. The measured maximum velocities at this distance had decreased to about only 4 fps.

30. The field measurements show that the zone of influence did not extend as high into the water column as anticipated nor were the maximum velocities as high as expected. The zone did extend a considerable distance horizontally with little drop in maximum velocities. Ambient velocities during the time of the field measurements were approximately 1 fps.

31. Based on these observations, it is not surprising that the fluidizer averaged 330 cu yd of material removed per hour instead of the predicted 16,000 cu yd per hour. As discussed in paragraph 14, the larger value was stated to be a short-term maximum by WPD and not an average long-term production rate. However, the discrepancy is much too large to attribute to this difference alone.

32. The theoretical and actual production rates were considerably different. During this exercise, insufficient data were collected to determine the precise sources of the difference. One significant known source of discrepancy was that the actual pump output was approximately 75 cfs instead of the 115 cfs used for theoretical predictions. Certainly, variations in the bottom elevation prevented the fluidizer from uniformly attacking the bottom, at least during initial passes. The ability of the hood to induce the fluidizer to act as an eductor was also not evaluated since its position was not altered during the measurements.

33. With the reduced velocities and attempts to remove the sand waves in 1-ft increments, the field exercise seemed to indicate that the fluidizer failed to transport the material very far horizontally. The sand was fluid-ized and placed in suspension. However, it apparently was redeposited down-stream of the jets. This was not a problem during the initial stages of the sand wave reduction. At this time, the crest of the wave was being attacked and the horizontal distance necessary to move the fluidized material was minimal. As the wave was reduced, the horizontal distance necessary to move the material in order for it to be deposited in the next trough increased. Apparently, at this stage the redeposited material tended to form a mound in front of the fluidizer boom. Eventually, the boom would ground and neces-sitate the dredge leverman raising the boom. This then created control problems for the tug captain and made maintaining a straight cut very difficult.

34. Though the fluidizer did not perform as well as expected, it did nevertheless reduce the sand waves and flatten the bed. The plant was easily mobilized and deployed and proved effective in restoring the navigation depth to the reach of the Columbia River in which it was deployed. The plant unit cost per cubic yard removed was $2.66. When other contract costs were added, the unit cost was $3.75. This is considerably more than conventional means, which range from $1.00 to $1.15 for this type of work depending on the dredge plant used.

Conclusions

35. The WPD jet fluidizer is an innovative approach to a nagging problem. Agitation dredging techniques are most effective in areas of

significant ambient current velocities and where fine-grained materials are encountered.* The environment of the Columbia River with its relatively coarse bed material and low ambient tidally influenced velocities provides a difficult testing ground for this dredge plant. The plant was rapidly deployable and mobile enough that it did not hinder navigation, but the production rate achieved was too low for the plant to compete economically with more conventional methods. More accurately evaluating theoretical performance may indicate modifications that would improve operation and production. However, with experience and improvements in deployment methodology, the plant could be a valuable asset for removing sand waves. The plant shows enough promise that further experimentation is warranted in the Columbia. Consideration should also be given to testing this plant in an environment of fine-grained material and/or higher ambient velocities.

Recommendations

36. While the plant failed to perform as expected, it did show promise as a quickly deployable and potentially effective means for reducing sand wave encroachment into the navigation channel on the Columbia River.

37. Further testing is warranted to maximize plant production. The following recommended alterations to the plant and the method of deployment should be investigated:

 a. Hood and jet nozzle angle. Testing different combinations of hood and jet nozzle angles would evaluate any eductor-type transport capability. Such testing could possibly be done in a laboratory and would yield the combination of angle settings for optimum movement of material.

 b. Removing smaller increments of material per pass. Attempting to remove smaller thicknesses of the bed per pass might result in increased overall production. A single pass can be completed within a few minutes. Therefore, shallower "cuts" may make maintaining the plant position much easier while avoiding mounding material in front of the boom.

 c. Increase pump output. Increasing plant flow capability with a larger pumping unit could improve production and better approach existing theoretical predictions.

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* T. W. Richardson. 1984. "Agitation Dredging: Lessons and Guidelines from Past Projects," Technical Report HL-84-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

d. **Operate plant in conjunction with higher ambient currents.**
    Operation during the high-flow season may significantly in-
    crease sediment transport distance and improve overall produc-
    tion. However, positioning the plant with the tug in a swift
    current may prove too difficult to achieve any production
    benefits.